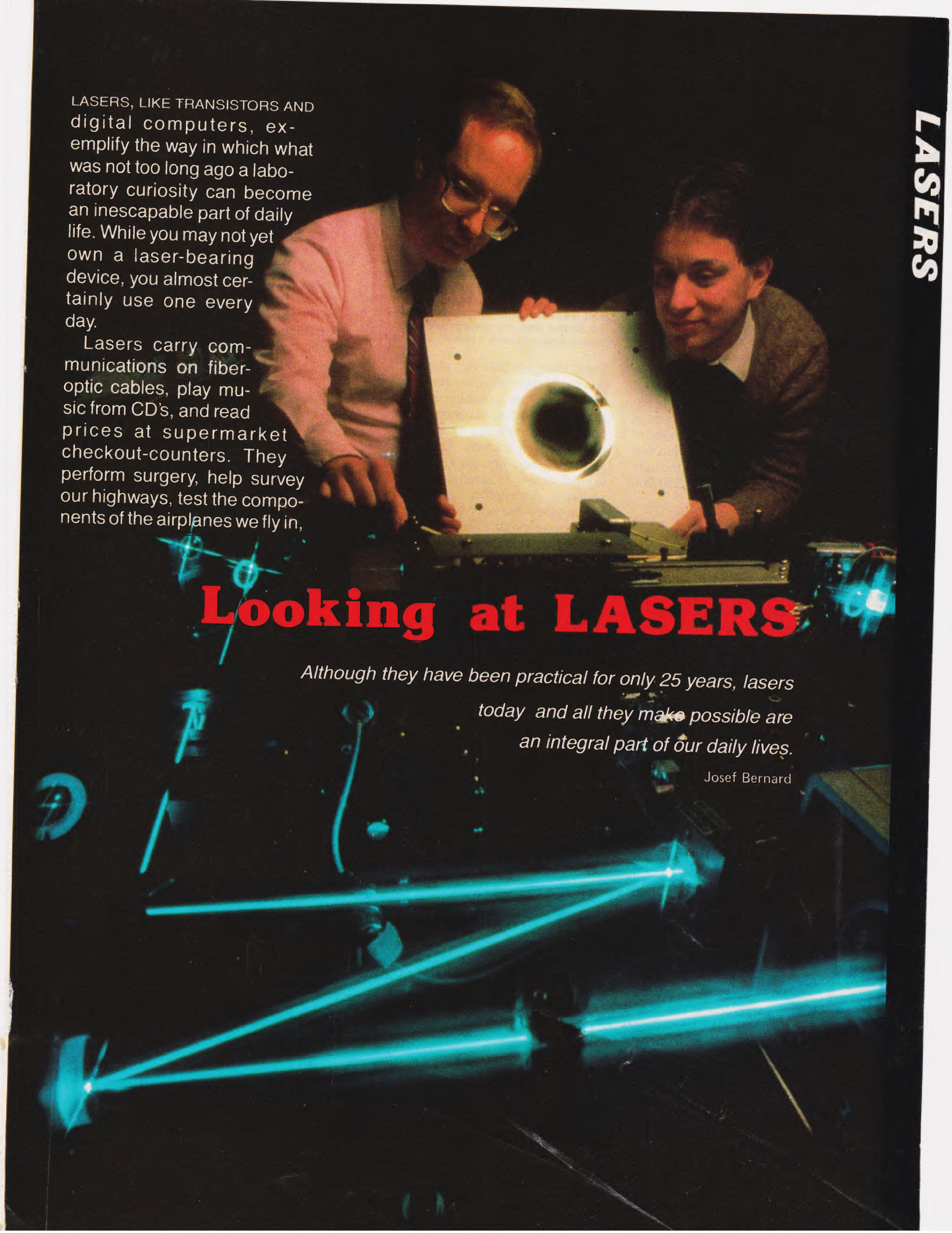


Looking at LASERS

Although they have been practical for only 25 years, lasers today and all they make possible are an integral part of our daily lives.

Josef Bernard

LASERS, LIKE TRANSISTORS AND digital computers, exemplify the way in which what was not too long ago a laboratory curiosity can become an inescapable part of daily life. While you may not yet own a laser-bearing device, you almost certainly use one every day.

Lasers carry communications on fiber-optic cables, play music from CD's, and read prices at supermarket checkout-counters. They perform surgery, help survey our highways, test the components of the airplanes we fly in,

and entertain us at rock concerts. They also make formidable weapons.

What is a laser?

A laser (which stands for *L*ight *A*mplification by *S*imulated *E*mission of *R*adiation) is a source of intense light that has several unusual and useful properties. The light is monochromatic, which means that it is a single, very pure, color whose frequency can be measured and used as a precision standard in and out of the laboratory. Laser light is coherent—all the waves of a beam are in phase. Unlike natural and most artificial light sources, whose emissions are incoherent, or phased randomly, a laser produces packets of photons all "marching in step", and possessing a great deal of energy. Finally, because of the way they are generated the rays of light produced by a laser are all parallel to one another, or very nearly so. A pencil-thin beam of laser light aimed at the moon will spread out to a diameter of only 1½ miles. That may not sound impressive—until you consider that the light would travel a distance of about 250,000 miles before diverging that far.

How lasers work

The principle behind the laser is called stimulated emission. That term refers to the fact that an atom, when in an excited state, can be made to emit a photon when bombarded by other photons or by another high-energy source such as a source of electrons.

That needs a little explaining. Figure 1-*a* shows a simple hydrogen atom—just a proton and an electron. The "height" of the orbit of the electron depends on the amount of energy that the electron is carrying and is very strictly defined by nature. Further, for an electron to be forced to jump from one orbit to another requires a precise amount of energy, or quantum, to be added to it.

In its lowest orbit, no energy has been added and the electron is in its normal, or ground, state. When just the right amount of energy is applied, the electron will jump to a higher orbit, and it is said to be excited (Fig. 1-*b*). That excited state, though, is unstable, so the electron quickly returns to its ground state. When it does that it gives up the energy that was applied to it, in the form of a photon, or particle of light. (Light is electromagnetic radiation but it frequently behaves like a particle. For that reason, a photon is sometimes called a "waveicle.") That spontaneous emission of photons is where laser light begins.

If you get enough excited atoms together, spontaneously emitting photons as they undergo the transition from the excited to the ground state, an interesting thing happens. When one of those photons strikes an already excited atom, it changes state and emits its own photon (Fig. 1-*c*).

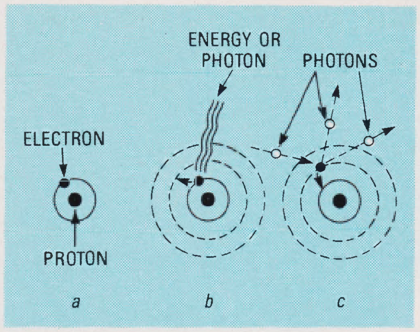


FIG. 1—A SIMPLE HYDROGEN ATOM is shown in *a*. If a precise amount of energy, or quantum, is added to the atom (*b*), the electron makes a transition from its normal ground state to a less-stable excited state and jumps to the next higher orbit. If a photon strikes the electron while it is in that excited state, the electron will return to the ground state and emit a photon of its own (*c*).

Thus, there are then two photons where previously there was one. Those two photons can go on to strike other excited atoms and generate still more photons—a process very much like what happens in a nuclear-fission reaction. That process of photons generating other photons from excited atoms is known as stimulated emission. A photon of a particular wavelength gives rise only to photons of the same wavelength. Thus, laser light is monochromatic; it contains only a single color.

The trick, of course, is to get together in one place a large number of excited atoms of the same kind, so the that stimulated emission of photons can take place. That is done by pumping the atoms in a material up to an excited state by bombarding them with intense light or with some other source of energy such as a beam of electrons. With a ruby laser—the type used by Theodore Maiman on July 7, 1960 when he demonstrated the first laser—as an example, let's examine the lasing process.

A simple diagram of a ruby laser appears in Fig. 2. The heart of that device is a rod of synthetic ruby whose ends are finely ground and polished so they are optically flat and are exactly parallel to one another. Both ends of the rod are silvered to reflect light back into it, but the reflecting surface at one end is not a perfect reflector—it allows perhaps ten percent of the light generated within the rod to escape. That light is the laser beam.

The rod is surrounded by a spirally-wrapped xenon flash tube similar to those used in electronic flash-units. The light produced by that tube will excite the atoms in the ruby rod. Because of that, that type of laser is known as an optically pumped laser. (As we shall see, there are other types of excitation commonly used.) The cooling equipment is present to remove the heat generated by the lasing device. Lasers are extremely inefficient—only one or two percent of the power they consume is transformed into usable laser light; the rest is given off as ordinary light and lots of heat. That isn't really too bad though—an ordinary incandescent bulb is only about two percent efficient, and the light it produces can't begin to compare with that from a laser.

When the flash tube discharges, the photons it emits enter the ruby rod through its sides and excite the material's chromium atoms, which absorb green and blue light. (Those atoms are what give the ruby its reddish color; you may remember from physics that whatever light a material doesn't reflect or transmit, it absorbs.) When those excited atoms decay from their excited state they give off photons, which trigger other excited atoms to release photons, and so on. The whole process in a ruby laser takes place in about 300 microseconds, and an intense burst of ruby-red light is produced.

We now have lots of light, but we still don't have a laser. That's where the reflective end surfaces of the rod come in. Most of the red light generated within the rod escapes through the sides, but some of it is reflected back into the rod, and that gives rise to the stimulated emission of more red light (hence the "amplification" in the word "laser").

A portion of the light is not reflected, however, but escapes from the rod through the end that is only partially silvered. That

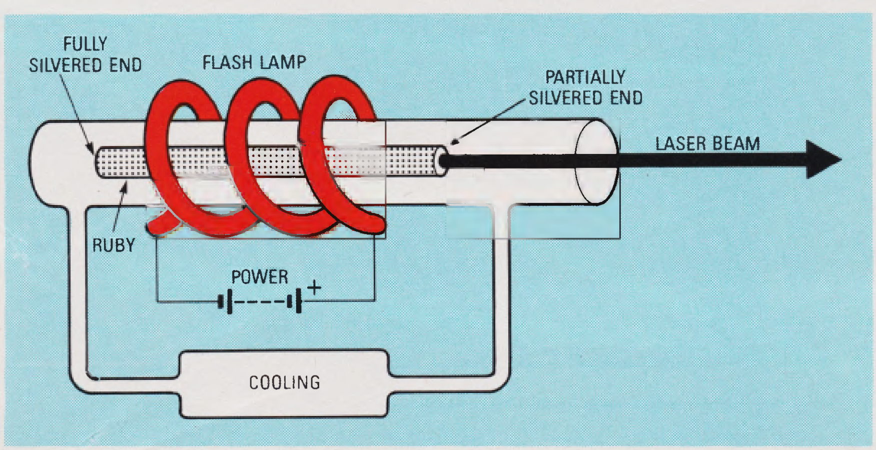


FIG. 2—IN THIS OPTICALLY-PUMPED LASER the light produced by a xenon flash lamp is used to excite the atoms in a ruby rod.

is the laser beam. It is monochromatic because the photons that trigger stimulated emission give rise only to photons like themselves. It is also coherent—all the light waves are in phase. That, too, is a result of the process of stimulated emission; the phase of the photons generated is identical to that of the stimulating photon. The rest of the light reflected by the rod's mirrored ends bounces back to interact with more chromium atoms and produce more photons.

Figures 3-*a* and 3-*b*, respectively, represent coherent and incoherent (random phase) light. As is the case with any wave phenomenon—we're now considering photons as waves rather than as particles—out-of-phase waves tend to cancel each other. Because all the waves of a laser beam are in phase, it is much more intense and powerful than a beam of ordinary incoherent light.

Finally, all of the photons in a laser beam travel parallel to one another. That is the result of the orientation of the reflecting surfaces at the ends of the lasing element. The beam of even an inexpensive laser has a divergence of only about one-twentieth of a degree, which means that the energy it carries is not diffused appreciably over distance.

There are many, many types of lasers, and their characteristics and modes of operation tend to overlap. The following examples are just a small cross section of what has been developed in the past 25 years.

Crystal lasers

This is the category to which the original ruby laser belongs. Those lasers are optically pumped and have a relatively low-power output, in the milliwatt range. The most common type is the neodymium-YAG (for *Y*trium-*A*luminum-*G*arnet) laser, which emits light in the near-infrared. YAG lasers can be operated continuously because the material from which they're made conducts heat, which would otherwise destroy the laser rod, relatively well.

Another member of the crystal-laser family is the neodymium-glass laser. It is less expensive to produce than the YAG type (glass is cheaper than garnet, even the synthetic kind), but it must be pulsed, or operated on a one-shot basis. It cannot sustain continuous operation because of glass's poor heat conductivity.

Gas lasers

There are more gas lasers than there are any other type. Over 5000 types of laser activity in gases are known. Gas lasers are not usually optically pumped, but are energized by passing an electric current at a potential of several thousand volts through the gas, which is contained in a tube with polished and silvered faces similar to the ends of the ruby rod described earlier. As

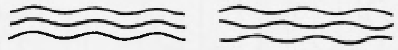


FIG. 3—IN LASER LIGHT, all of the waves are in phase; thus they are said to be coherent (*a*). In normal light, the waves have no phase relationship (*b*).

the current flows through the gas, the electrons transfer some of their energy to it, bringing it to a state where the stimulated emission of photons can occur. Because of the way they're constructed, gas lasers can be cooled more efficiently than crystal types, and lend themselves better to continuous operation.

The most widely used gas laser is the helium-argon laser, which can be built for a modest sum by almost any experimenter. It is able to produce no more than 50 milliwatts, but its tight beam of red light, about a millimeter across, makes it ideal for laboratory and experimental use.

Argon and krypton lasers can produce a wide range of colors, but are still relatively low in power. It is not feasible, for example, to construct an argon laser more powerful than 100 watts. Argon lasers with their green light are frequently used in medical applications.

The infrared carbon-dioxide laser is more of a heavyweight. It can have an output as high as several hundred kilowatts. Moderate-sized lasers of that sort are widely used in industry.

Liquid lasers

Organic dyes dissolved in organic compounds such as alcohol can be made to lase, too. Organic lasers are unusual in that one laser can produce a wide range of colors. That spectrum can be optically tuned, and a very precise selection of light of a single color can be made. That capability makes the dye laser a very valuable laboratory tool.

Semiconductor lasers

Semiconductor lasers (Fig. 4) are members of the LED family. They differ from ordinary LED's in that they consume considerably more current and the edges of the semiconductor die are polished to form interior reflecting surfaces. Because of their extremely small size—about as big as a grain of salt—and the difficulty of removing the heat they generate, those lasers do not have a very high output. Still, there are many applications to which they are well suited, among them fiber-optic communications and compact-disc players.

Laser applications

In the 25 years since they came into existence, lasers have proven themselves invaluable in a diverse range of fields. Here are a few of them:

Industry: The high temperatures produced by focused laser beams make them excellent tools for welding, cutting, and drilling. A pinpoint of coherent light can cut or bore much more cleanly than its mechanical equivalent, with much less waste. (An informal, and entirely unofficial, system for rating the strength of lasers measures their power in terms of "Gillettes"—the number of razor blades that a beam of laser light can successfully punch through.)

Photographs taken by laser light can be used to determine stress regions and faults

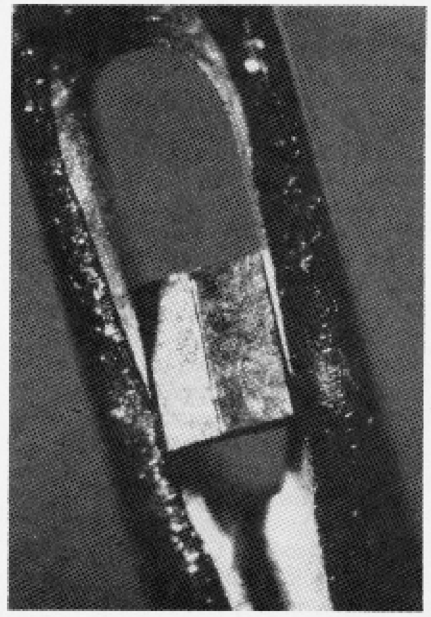


FIG. 4—THIS SEMICONDUCTOR LASER is so tiny that it can fit in the eye of an ordinary sewing needle. Photo courtesy of ATT Bell Laboratories.

in materials, simplifying and improving quality control procedures in critical applications. Lasers are also used in industry for non-contact monitoring of a wide variety of systems. See Fig. 5.

Medicine: Lasers find applications in numerous areas of medicine, among them dermatology, gynecology, and many areas of surgery. The finely focused beam of a laser can operate in areas (such as the inside of the eye) inaccessible to the traditional scalpel.

Science: Lasers have helped scientists both to refine existing knowledge and to learn more about our universe. Using lasers, it has been possible to determine

FIG. 5—LASERS HAVE many applications in industry. Here's a device that uses a laser to monitor the performance of an ultrasonic wire bonder, which is used in electronics production.

the speed of light (186,282.398 miles/second; 299,792.458 kilometers/second) with an accuracy hitherto unknown, and other units of measures have also benefited. A laser beam follows what must be the world's straightest line, a boon for surveyors and the like. Lasers in the laboratory have also allowed the development of new techniques to perform tasks that were previously impossible. Nuclear fusion reactions making possible the generation of enormous quantities of inexpensive electricity from plain seawater will probably be initiated and sustained by lasers.

Communications: Right now fiber-optic communications links using semiconductor lasers are in limited use, but their potential for carrying vast quantities of information makes it certain that as new installations are made, they will become much more common. In space, where laser light cannot be attenuated by air, it may carry communications and data from satellite to satellite, or even to earth. Lasers also are the heart, of course, of the laser printers; those devices, with their high-quality outputs, are now becoming popular in computer circles.

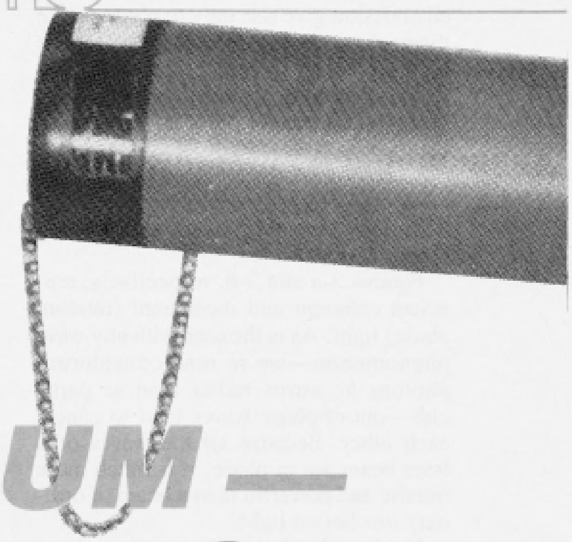
Entertainment: Laser-light shows are popular at rock concerts, and lasers are also used to record and read the information contained on CD's and most videodiscs. Holography, practical only with laser light, makes possible 3-D photography without a camera or special viewing device, and has given birth to a new art form. One day we may enjoy holographic movies, although holographic television at this point seems rather farfetched because of the limited resolution of even the most sophisticated video systems. The applications of holography, of course, are not limited to the world of entertainment. Holographic techniques are also used in devices like scanners for UPC (*U*niversal *P*roduct *C*ode) readers in stores, and in the restoration of artwork.

War: Like dynamite, lasers can be put to both peaceful and destructive uses. Currently in the headlines is the "Star-Wars" technology that will take the science of war into the peace of space. Lasers are also used in the navigation systems of missiles and in targeting devices.

New uses for the unique qualities of laser light are constantly being conceived. Among some of the more unusual and esoteric areas being explored are dental holography, gene manipulation, acupuncture, laser-based optical computers, and the use of lasers to transmit power from solar-energy-gathering satellites. Future applications of the laser may only be limited by the scope of human imagination.

It doesn't take much to see that the invention of the laser is one of the most significant things to come out of the laboratory in this century. **R-E**

BUILD THIS



HELIUM–NEON LASER

Build this simple helium-neon laser and start having fun with photons!

ROBERT GROSSBLATT and ROBERT IANNINI

BACK IN THE HEYDAY OF SCIENCE FICtion's era of purple prose, tales of bug-eyed monsters, death rays, and the like filled many a pulp magazine. Of course, we knew then that it was all just fantasy; you could no more have a "death ray" than you could travel faster than sound or put a man on the moon.

While those bug-eyed monsters (or BEM's, for short) have yet to pay us a visit (to the best of our knowledge), much of yesterday's science fiction is today's science fact. We even have a death ray, of sorts. Of course, we are referring to the laser, which can be a powerful weapon in the hands of those who wish to use it as such.

But the laser is also a great tool for science and industry. In just 25 years the laser has gone from far-fetched notion, to scientific reality, to common noun. Hardly a day goes by where some part of our lives is not affected by lasers. Today, the laser has joined the transistor as a hallmark of modern electronics.

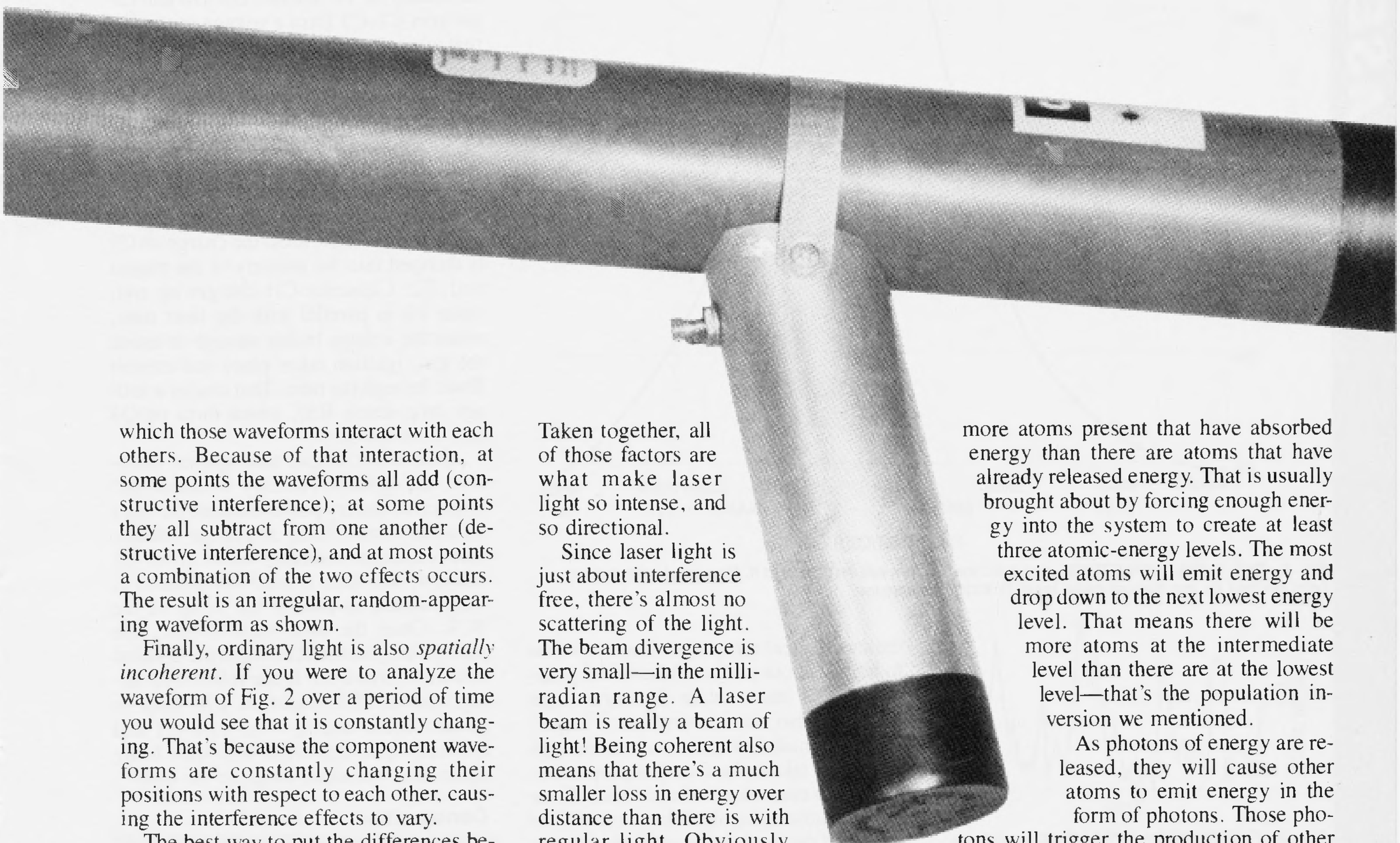
What's a laser?

The word *laser* is an acronym for *L*ight *A*mplification by *S*imulated *E*mission of *R*adiation. But for most of us, that provides a poor explanation of what a laser is and how it works. To find a better explanation, we have to leave electronics for a while, drop into the world of physics, and talk a little bit about the nature of light. You can't understand laser light until you have some familiarity with the properties of light in general.

There are three ways in which laser light differs from ordinary light, and each of those differences contributes to the special characteristics of a laser. Let's begin by looking at some of the characteristics of ordinary light.

Ordinary light has a relatively wide bandwidth. That means that a spectrographic analysis would reveal that regular light is made up of many different wavelengths. Just about everybody has seen, or done, the experiment in which a beam of white light is directed through a prism and split into different colors. The ordinary light we see as white, therefore, is actually made up of different color elements—it's *polychromatic*. Figure 1 shows the composition of visible light, and the relative sensitivity of the human eye to various wavelengths.

Ordinary light is also *temporally incoherent*. By that we mean that the various components of the light do not share any time relationship; they are all randomly out-of-phase with respect to each other. Thus, if you were able to look at the waveform of a beam of ordinary light, you would see something that looks like Fig. 2. The irregularity and random appearance of that waveform is caused by the presence of waveforms of differing frequencies in the light, and the ways in



which those waveforms interact with each others. Because of that interaction, at some points the waveforms all add (constructive interference); at some points they all subtract from one another (destructive interference), and at most points a combination of the two effects occurs. The result is an irregular, random-appearing waveform as shown.

Finally, ordinary light is also *spatially incoherent*. If you were to analyze the waveform of Fig. 2 over a period of time you would see that it is constantly changing. That's because the component waveforms are constantly changing their positions with respect to each other, causing the interference effects to vary.

The best way to put the differences between ordinary and laser light in perspective is to compare light to sound. Ordinary light, because of all the things we just talked about, can best be compared to noise. The waveforms at any moment in time are not only randomly spaced, but there's an unpredictable mix of frequencies as well.

Now, if regular light is like noise, then laser light can only be thought of as the purest sound imaginable. For openers, laser light is highly monochromatic—a spectrographic analysis would show that it is composed of light of only one wavelength. And where regular light is temporally incoherent, a laser is temporally coherent—all of the light waveforms are in phase with each other. That is one of the reasons why a laser puts ut light of such pure color. Being monochromatic helps, of course, but being temporally coherent as well means that there's almost a complete absence of what would be called distortion in a sound wave.

As you might have already guessed, laser light is also spatially coherent. If you looked at the waveforms over a period of time, there would be absolutely no shifting or movement. Considering the absence of interference effects, that is exactly what you would expect to happen. Taken together, all of those factors are what make laser light so intense, and so directional.

Since laser light is just about interference free, there's almost no scattering of the light. The beam divergence is very small—in the milliradian range. A laser beam is really a beam of light! Being coherent also means that there's a much smaller loss in energy over distance than there is with regular light. Obviously, since laser light is so different from regular light, it can't be produced the same way. And in order for us to understand how it's produced, let's see how regular light is produced.

Electromagnetic waves in general, and light in particular, is produced when an atom gives off energy. Now, an atom either takes on energy (absorption), or gives off energy (emission), by having its electrons move from one energy level to another. Once energy has been supplied to the system, and absorbed by the atom, emission can occur in one of two ways—it can happen spontaneously, or it can be stimulated.

Spontaneous emission is the result of natural atomic decay. The electrons randomly drop in energy level and produce the kind of waveforms shown in Fig. 2. When you power up a light bulb, for example, the atoms in the filament absorb energy and release it as a combination of heat and ordinary, incoherent light.

Stimulated emission is a completely different process. The idea is to keep the atoms from releasing their absorbed energy in a random manner. In order to do that, you have to create a state of affairs called a "population inversion." In simple terms, that means that there have to be more atoms present that have absorbed energy than there are atoms that have already released energy. That is usually brought about by forcing enough energy into the system to create at least three atomic-energy levels. The most excited atoms will emit energy and drop down to the next lowest energy level. That means there will be more atoms at the intermediate level than there are at the lowest level—that's the population inversion we mentioned.

As photons of energy are released, they will cause other atoms to emit energy in the form of photons. Those photons will trigger the production of other photons. And if the emission is bounced back and forth between two mirrors the production of photons will continue to build in phase and the result will be, you guessed it, a beam of laser light with a waveform that looks like that shown in Fig. 3.

Making a laser

Now, understanding the basic theory and putting it into practice are, as we all know, two completely different things. Creating the population inversion you need to produce a laser beam is really an iffy, ticklish business. Everything has to be just so or nothing will happen. The mirrors have to be of a certain type to produce the in-phase coherent energy needed for a laser. And enough energy of the right type has to be forced into the system to make the whole thing work.

The kind of energy you have to pump into the system depends on the type of material you're trying to make lase. Semiconductor and gas lasers are pumped up with electrical energy while crystalline lasers, such as those made from ruby rods or YAG (*Y*trium-*A*luminum-*G*arnet) are usually pumped up optically with xenon flash tubes or arc lamps.

The laser we're building here is a gas

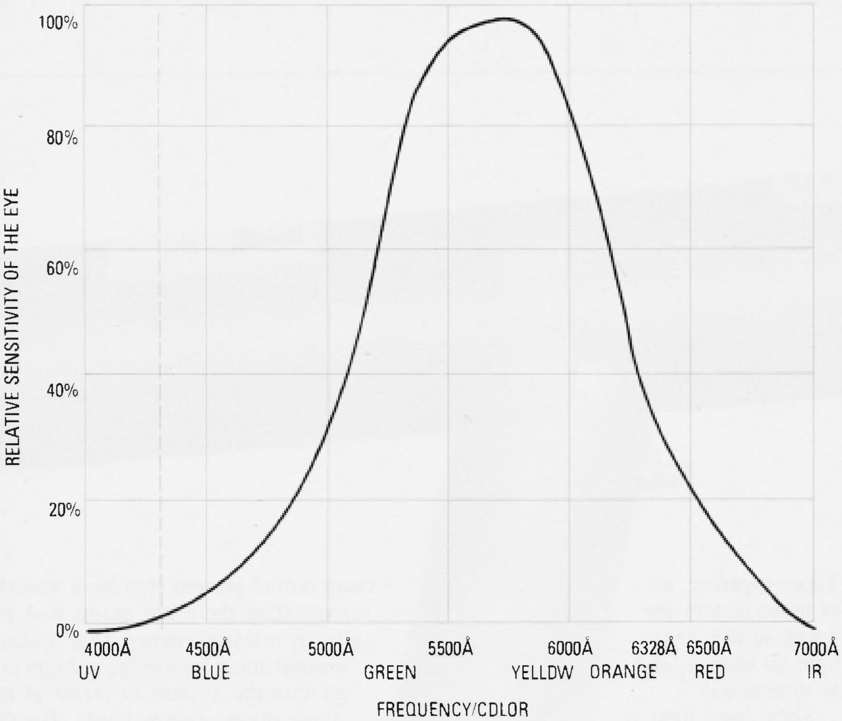


FIG. 1—THE VISIBLE SPECTRUM, and how the human eye responds to it. The wavelength of the light emitted by our helium-neon laser is 6328 Angstroms.

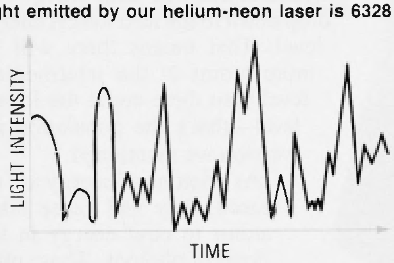


FIG. 2—THIS RANDOM-APPEARING waveform is that of ordinary light. The waveform is made up of all of the various frequencies that make up such light.

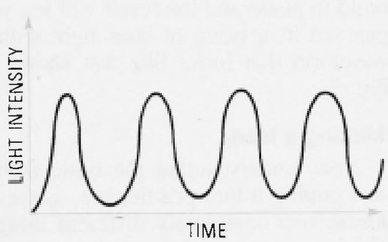


FIG. 3—LASER LIGHT is made up of light of just one frequency. It is the purest type of light possible.

laser—more specifically a helium-neon laser. The frequency of the light is 6328 Angstroms and the laser puts out about 1 milliwatt with a beam divergence of 1.3 milliradians. Now, 1 milliwatt may not sound like a lot of to you, but that's because you're still thinking in terms of regular light. Remember that the laser produces a highly directional beam of coherent, monochromatic light. The laser we're talking about here generates a beam that can be spotted on a wall more than two miles away!

Helium-neon lasers are extremely inefficient and, in order to make them work, the mechanical setup of the laser tube has to be just about perfect. It has to be properly sealed and contain the correct gas mixture. Also, the mirrors have to be perfectly aligned dielectric ones so enough reflection takes place at the proper frequency to cause the device to lase. Those mirrors must be highly reflective, within a couple of decimal places of 100%; by contrast, the silver mirrors we use every day have a reflectance factor of only 95%.

Making a helium-neon laser tube is a project that is beyond the means of most of us as it requires a fair amount of skill and equipment. Among other things, you need to have the skills and equipment required to create a precise mixture of gasses, and you need to be adept at glass blowing. All of that is not impossible, of course, but in most cases its a task that is best left to someone else; we recommend that you purchase rather than build a tube. (One source for laser tubes is mentioned in the Parts List.)

Once you have a working laser tube, actually making it produce a beam is surprisingly simple. The only electronic assembly needed is a power supply that will deliver the right voltage to make the tube fire. Figure 4 is the schematic of a power supply that can be used to trigger the laser. If it looks familiar, that's because its front end is essentially the same one used in the construction of the infrared viewer that appeared in the August 1985 issue of **Radio-Electronics**.

The power supply is a switcher with Q1, Q2, and their related components forming an oscillator that switches a squarewave through the primary windings of T1, a high voltage step-up transformer. That part of the circuit takes the battery voltage and produces about 400 volts AC at the secondary of T1. Diodes D3–D6 and capacitors C2–C5 form a voltage multiplier that takes the 400 volts from T1 and boosts it to the 1600-volts DC needed to ignite the laser tube.

The high-voltage pulse needed to ignite the tube comes from an 800-volt tap on the voltage multiplier. Resistors R3 and R4 divide that voltage to provide the 400 volts needed to charge up C9, the dump capacitor. When the SCR fires, the charge on C9 is dumped into the primary of the trigger coil, T2. Capacitor C11 charges up and, since it's in parallel with the laser tube, when the voltage builds enough to excite the gas, ignition takes place and current flows through the tube. That causes a voltage drop across R10, which turns on Q4 and turns off Q3.

As soon as the laser tube ignites, therefore, the ignition circuitry is turned off. That saves battery power because the laser tube can sustain firing at a lower voltage. The relaxation oscillator made up of Q3 and Q4, and their related components is only needed to control the firing of the SCR. Once the tube starts to lase, the voltage drop across R10 keeps the ignition circuitry turned off. If the tube stops lasing, the R9–R10 junction will drop to ground again and Q4 will turn off and unclamp Q3. The SCR will start firing again and, we hope, re-ignite the tube.

Construction

Before we actually start building the circuit, there's one very important thing you *must* keep in mind:

CAUTION! The power supply can produce as much as 10,000 volts at about 5 milliamps. That is enough juice to do a lot of damage. If you're not careful you can give yourself a severe shock. Remember that the capacitors take a while to discharge completely. You can get a real jolt even if the circuit has been turned off for five or ten minutes. Treat the circuit with respect and make sure to discharge the capacitors if you want to do some work on the circuit.

Now that that's out of the way, you can build the power supply on perfboard or use the PC board that's provided in our PC Service section, elsewhere in this magazine. If you use perfboard, remember to keep the leads as short as possible because there's a lot of high-frequency AC running around part of the circuit. Whichever method you use, make sure to keep any metal objects and your fingers away from the output section located around T2 and R11. Those are the points of the circuit where the highest voltages can be found. One short second of carelessness on your part and you're going to get zapped. If you're lucky, all it will do is hurt a lot.

The only other components in the cir-

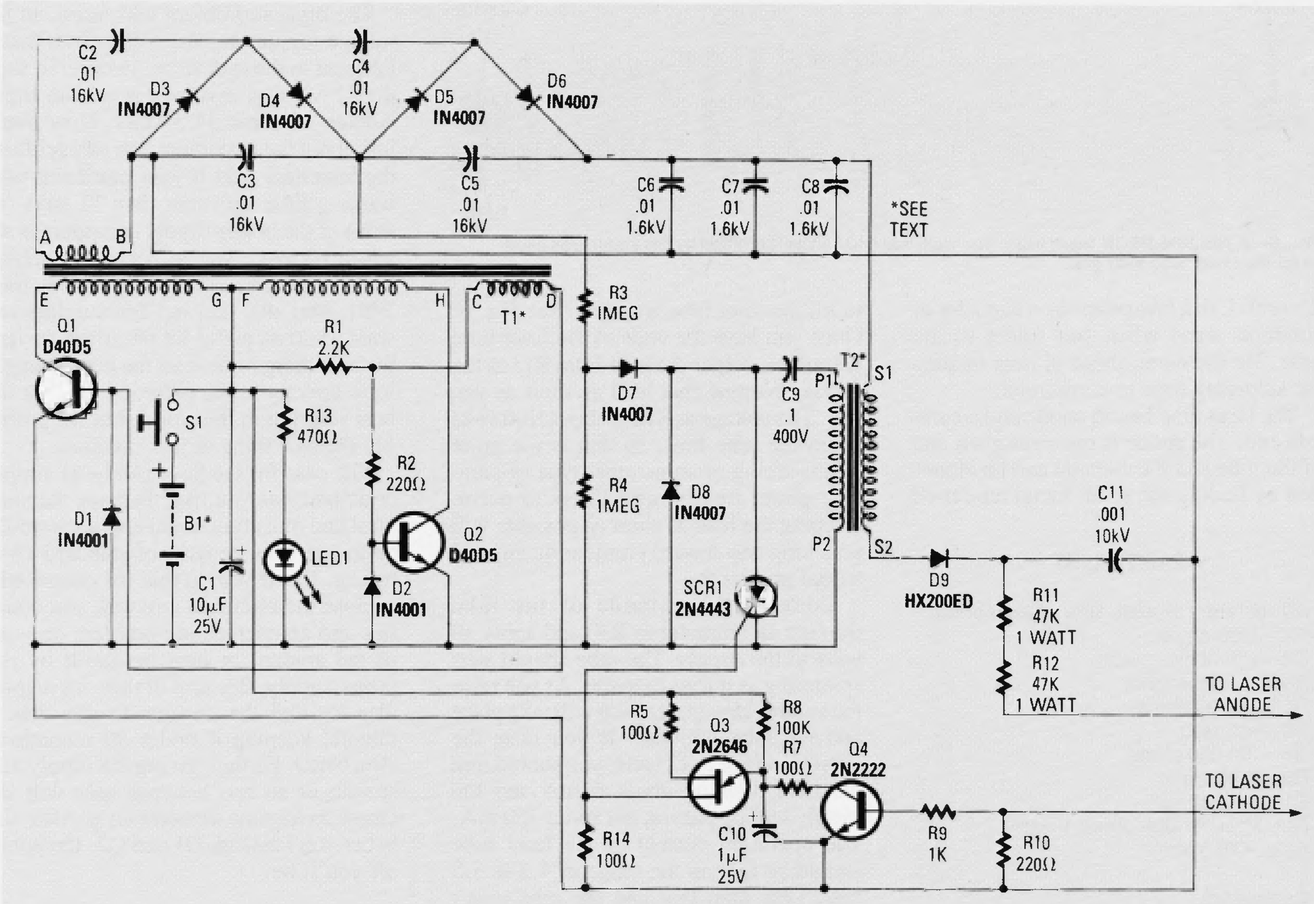


FIG. 4—THIS POWER SUPPLY is all you need to drive a laser tube like the one available from the supplier mentioned in the Parts List.

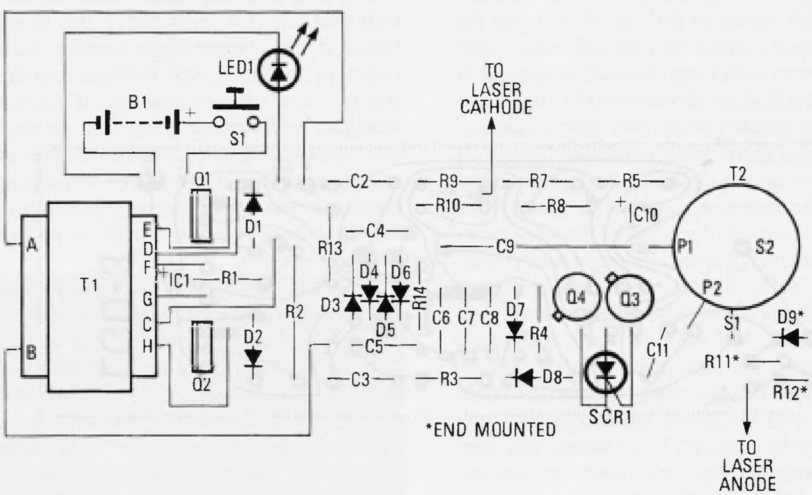


FIG. 5—IF YOU CHOOSE to use the PC board provided in our PC Service section, use this parts-placement diagram.

cuit that require special attention are the switching transistors, Q1 and Q2. The maximum current draw from the batteries is about 750 mA, so those transistors will be handling a lot of juice and getting hot. The PC-board layout shown in Fig. 5 is designed so that the transistors can be placed in such a way that their tabs can be stuck against the laminations of T1. If you are using perforated construction board, be sure that your layout allows for that, too. Use some heat-sink compound to get good thermal contact, and using small heat sinks wouldn't be a bad idea.

After you've identified the components and found their position on the board, solder them in using a minimum of solder. Once you've done that, use some high-voltage putty, paraffin, or varnish to cover the traces (or wires if you're using perfboard) that connect to all the components on the secondary side of T2 and the laser tube. That part of the circuit has the highest voltages and it's likely that arcing will take place if all the bare metal isn't covered. You may find it necessary to use the same material on the component side of the board as well.

When you finish the board, check for bridges, opens, bad solder joints, and so on. If everything seems OK, you're ready to test the power supply. Take the two leads that normally would go to the laser tube and tape them down so that they're ⅛-inch apart. Connect 10 volts to the power supply. You should see arcing across the laser-tube leads at a rate of about once a second or so; the circuit should be drawing approximately 250 mA. If the spark becomes continuous, the current draw should jump to about 750 mA—the full operating current of the laser tube. If you measure the voltage across the output of the supply, you should see an open circuit voltage of about 2500. Once the laser tube is connected, the voltage will be in the neighborhood of 1500.

If you've gotten this far without any brain damage, you're ready to connect the tube to the supply.

CAUTION! The laser tube is an expensive, delicate piece of equipment. In order to connect it to the circuit you'll be soldering leads to the metal collars at either end of the tube. Use a minimum of solder and apply heat for a minimum amount of time. Don't ever forget that the tube has a high vacuum inside and you can damage more than the tube if you destroy the integrity of

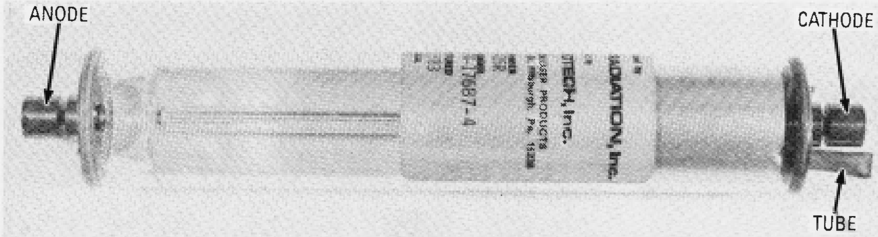


FIG. 6—A HELIUM-NEON laser tube. The cathode end can be identified by the small tube used to fill the laser tube with gas.

the seal. Use a low-power iron and a lot of common sense when you solder to the tube. Tin the wires ahead of time to keep the soldering time to a minimum.

The laser tube has an anode and a cathode end. The anode is the clear glass end of the tube and the cathode can be identified by finding the small metal tube used

PARTS LIST

All resistors ¼ watt, 10% unless noted
R1—2200 ohms
R2—220 ohms, 1 watt
R3, R4—1 megohm
R5,R7—100 ohms
R6—not used
R8—100,000 ohms
R9—1000 ohms
R10—220 ohms
R11, R12—47,000 ohms, 1 watt
R13—470 ohms

Capacitors
C1—10 µF, 25 volts, electrolytic
C2–C8—0.01 µF, 1.6 kV, ceramic disc
C9—0.1 µF, 400 volts, paper dielectric
C10—1 µF, 50 volts, electrolytic
C1—0.001 µF, 10 kV, ceramic

Semiconductors
D1, D2—1N4001
D3–D8—1N4007
D9—HX200ED, 20 kV diode
LED1—Red LED
Q1, Q2—D40D5, NPN power transistor
Q3—2N2646—UJT transistor
Q4—PN2222 NPN transistor
SCR1—2N4443 SCR

Other components
T1—12 to 400 volts, 10 kHz switching transformer
T2—10-kV trigger transformer, 400-volt primary
B1—14.4 volts, 12 nickel-cadmium cells, or equivalent
S1—SPST switch, momentary pushbutton, normally open

Miscellaneous: PC board, helium-neon laser tube, PVC tubing for case, battery holders, wire, solder, etc.

Note: The following are available from Information Unlimited, PO Box 716, Amherst, NH 03031: PC board, $4.50; switching transformer (T1), $14.50; trigger transformer (T2), $11.50; 1-milliwatt laser tube, $149.50; 0.4-milliwatt laser tube, $99.50; high-voltage diode (D9), $3.50; high-voltage capacitor (C11), $3.00.

to fill the laser tube with gas. See Fig. 6. Once you have the ends of the laser tube identified, solder the lead from R12 to the anode, keeping that lead as short as you can. The voltage at R12 is about 1100 volts when the tube fires, so that is the point where arcing or some other type of parasitic power loss is most likely to occur. Keeping the lead as short as possible will go a long way toward eliminating any potential problems.

Connect the cathode of the tube through an ammeter to R10 and apply 10 volts to the supply. The tube should start sputtering as it tries to ignite. As you raise the voltage *slowly*, ignition will take place and the tube will fire. If you raise the supply voltage to 12 volts, you should find the tube drawing about 5 mA and the supply will be putting out about 750 mA. The operating current of the laser tube should be kept in the range of 4.5 to 5.5 mA. Less than that and the tube won't operate reliably; more than that and you'll cut down its operating lifetime. You can trim the values of R11 and R12 to get the operating current into the safe range. Just make sure you keep the total resistance of R11 and R12 at about 100,000 ohms.

The current through the tube is going to vary a lot as the battery voltage changes. If you use nickel-cadmium cells, remember that the operating voltage is going to be 1.2 in each cell for most of the lifetime of each charge. Freshly charged nickel-cadmium cells, however, can have a voltage as high as 1.5. Admittedly that doesn't last very long, but we'll mention it because adjusting the laser tube's operating current with freshly charged batteries could cause you to choose artificially high values for R11 and R12. So before you start trimming the resistors, make sure the batteries are at 1.2 volts per cell

Since the operating current is tied to the supply voltage, it's natural to think about voltage regulation. Well, there is nothing wrong with regulating the input voltage, but there are a few things to keep in mind. If you use 12 nickel-cadmium cells, you'll have a supply voltage of 14.4 and you'll be drawing as much as 750 mA from that supply. A three-terminal regulator like the 7812 would seem to be an ideal choice, but asking it to supply 750 mA is really asking a lot unless you use a 7812C, which can handle 1 amp with a good heat sink. An LM317 can be set up to put out 12 volts and it can supply 750 mA.

The biggest problem with using an IC voltage-regulator is the voltage loss that's inherent in those devices. In order to supply 12 volts, a regulator needs an input voltage of about 14.5 volts. Now that's just about the maximum you can get from the batteries. And if your particular tube wants a little bit more than 12 volts, or some of the power-supply components are a little bit lossy, you're in a lot of trouble.

So, you ask, what's the bottom line. Well, after all's said and done, unless you want to do an awful lot of circuit design, the best thing to do is let the power supply look directly at the batteries. It's not the best solution in the world, but it's probably the best thing in this situation.

The case for the laser can be as simple or as fancy as you like. Perhaps the simplest and most functional approach would be to use some lengths of standard PVC tubing. But if you do that, or completely enclose the circuit in any way, you could run into an overheating problem because of the amount of heat produced by the power supply. Because of that, it's a good idea to limit the on-time to less than a minute; keeping it under 30 seconds is even better. Further, giving the supply a 5-second or so rest between uses will increase its lifetime tremendously. Also, the better you heatsink Q1 and Q2, the better off you'll be.

Having fun

The output of the laser tube is about 1 milliwatt (or 0.4 milliwatt if the lower-powered tube offered by the supplier mentioned in the Parts List is used) and, at that power, it can't do any damage. If you had thoughts of burning your way through steel, forget it. Lasers that can do that are worlds away from the one we're building. However, that doesn't mean you can treat the light from this laser with no respect whatsoever.

CAUTION! Even a 1-milliwatt laser can be hazardous if you look directly at the beam. While we assume that anyone considering building a laser would know enough about those devices to never, never even consider doing something so foolhardy, the very nature of laser might make it very easy for accidents to happen. The beam is highly directional and very intense; to compound matters, the reflected beam is just as dangerous as the emitted beam. It's a simple matter to have the beam bounce off some shiny object and reflect back to you. You can wear safety glasses, but even if you do, be careful where and how you use the laser.

While you can use this laser, which throws an intense red beam, for such things as target spotting, perhaps its greatest use is as an introduction to the world of lasers in general. Watching the tube fire is truly fascinating and the more you experiment with it, the more you'll learn. **R-E**